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Stratigraphic and Paleobotanical Evidence for Prehistoric Human-Induced Environmental Disturbance on Mo'orea, French Polynesia[1]

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ABSTRACT: Humans played an important role in modifying the prehistoric environments of most Pacific Islands. In this paper we reconstruct the role of Polynesians in transforming the late Holocene landscape of the 'Opunohu Valley, Mo'orea, Society Islands (French Polynesia). Stratigraphic, sedimentary, chronometric, and paleobotanical evidence are used to reconstruct a sequence of geomorphological and vegetation changes during the past 1500 yr. Our results indicate substantial human inputs to landscape changes in the 'Opunohu Valley during the late Holocene. Vegetation burning in the upper 'Opunohu Valley, possibly for agricultural purposes, led to conversion of primary forests into early successional forests and degraded fernlands. Erosion of slopes in the upper valley led to massive deposition of sediments onto the valley floor, thus transforming the valley bottom swamp into a relatively dry alluvial flat. These results contribute substantially to an appreciation of the role played by the indigenous Polynesian people in modifying the Society Islands ecosystems and landscapes.

BIOGEOGRAPHERS HAVE LONG observed that the remote Pacific Islands are highly susceptible to disturbance; Fosberg (1963: 559) asserted that the most distinguishing aspect of oceanic islands "is their extreme vulnerability, or susceptibility, to disturbance." Until recently, it was thought that the greatest disturbance followed European colonization, and that the impact of the prehistoric, indigenous populations on Pacific Island ecosystems was minimal. This viewpoint reflected a persistence of eighteenth-century notions of "the noble savage," in which preindustrialized peoples are regarded as having been closely integrated with nature and had no impacts on their environment. Nowhere has this conception been more evident than in the Society Islands of East Polynesia, where European naturalist-voyagers such as Joseph Banks and J. R. Forster believed that they had found ethnographic proof of Rousseau's utopian vision. The notion that the indigenous Tahitians had scarcely modified their island environment was promulgated by no less an observer than Darwin (1957: 367), who regarded the zone of human impact as "no more than a fringe of low alluvial soil ... round the base of the mountains," where the Tahitians cultivated their crops.

Interdisciplinary work by archaeologists, palynologists, and paleontologists over the past 20 yr has now greatly modified our understanding of the role of indigenous human populations in changing Pacific Island environments during the Holocene. Evidence from Hawai'i, New Zealand, Easter Island, Mangaia, Tikopia, Aneityum, Fiji, and other localities has demonstrated such substantial

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prehistoric human impacts as massive deforestation, expansion of degraded fernlands, erosion and alluvial extension of coastal plains, and faunal depletion and extinction, especially of endemic avifauna (e.g., Hughes et al. 1979, Kirch and Yen 1982, McGlone 1983, 1989, Kirch 1984, Olson and James 1984, Spriggs 1985, Steadman 1989, Flenley et al. 1991, Kirch et al. 1992).

This study reconstructs late Holocene landscape in the ʻOpunohu Valley, Moʻorea, Society Islands, focusing on the role of prehistoric humans. This was one facet of a larger research program focused on the prehistoric agricultural systems of the Society Islands (Lepofsky 1994). We present stratigraphic, sedimentary, and paleobotanical evidence from the ʻOpunohu Valley, and reconstruct a sequence of geomorphological and vegetational changes during the past 1500 yr. In conjunction with recent palynological and zooarchaeological studies in the Society Islands (Steadman 1989, Parkes and Flenley 1990), our findings contribute considerably to an appreciation of the substantial role played by the Polynesian people in modifying the Society Islands ecosystem.

The Research Setting

ʻOpunohu Valley is the larger of two deeply embayed, amphitheater-headed drainages on the northern side of Moʻorea Island (Figures 1 and 2). The ʻOpunohu drainage basin incorporates an area of 1500 ha, with ca. 800 ha consisting of relatively low-lying floodplain. The steep colluvial slopes and mountainous ridges rimming the valley floor rise to elevations of 700 m. The interior portions of the valley are divided into two main sections, Amehiti on the west and Tupauruuru on the east. Rainfall is heavy, ranging from ca. 2500 mm at the coast to >3200 mm in the upper valley (Lafforgue and Robin 1988). With such heavy rainfall, combined with the steep topography of the mountain ridges, flash floods are relatively common, and both mass wasting and high-energy fluvial processes are important factors in the erosion, transport, and deposition of sediments within the drainage system.

The ʻOpunohu Valley floor consists of organically rich colluvial and alluvial sediments used today primarily for grazing (SETIL 1962). Forested areas in the lower valley are dominated by Tahitian chestnut, *Inocarpus fagifer* (Parkinson) Fosberg, and *Hibiscus tiliaceus* L. The higher colluvial slopes are largely covered in *Inocarpus* forests with sparse understory cover. Stands of *Dicranopteris linearis* (Burm. f.) fernland occur on the higher ridges and knolls, and are associated with laterized soils virtually lacking an A-horizon. At the bases of the steep mountains, stands of candlenut, *Aleurites moluccana* (L.) Willd., occur, and the smaller stream watercourses support a denser forest vegetation dominated by *Inocarpus*, *Hibiscus*, and small *Syzygium malaccense* (L.) Merr. & Perry.

It is notable that most of the vegetative dominants listed above are either Polynesian introductions or species that are known to thrive in disturbed environments. *I. fagifer* and *S. malaccense* are Polynesian tree crops of Indo-Malaysian origin (Whistler 1991), and *Inocarpus* is known archaeologically to have been transported into the Pacific by the Lapita people (Kirch 1989). *Aleurites moluccana* is most likely an aboriginal introduction of Southeast Asian origin, and *H. tiliaceus* is a widespread plant that may have been spread by Pacific peoples (Fosberg 1991, Whistler 1991). *Dicranopteris linearis* is an indigenous fern, probably dispersed naturally, but which thrives in anthropogenically disturbed habitats. *Dicranopteris* fernlands, in particular, have been shown to have expanded dramatically on such islands as Lakeba, Futuna, and Mangaia after Polynesian occupation and forest clearance (Hughes et al. 1979, Kirch et al. 1992, Kirch and Ellison 1994). In sum, the modern vegetative dominants of the ʻOpunohu Valley are those characteristic of anthropogenically disturbed and agriculturally modified Pacific environments. Determining when this anthropogenic vegetation became established was one goal in our reconstruction of the late Holocene landscape of the ʻOpunohu Valley.

Eustatic fluctuation in relative sea level, locally complicated by variable tectonic pro-

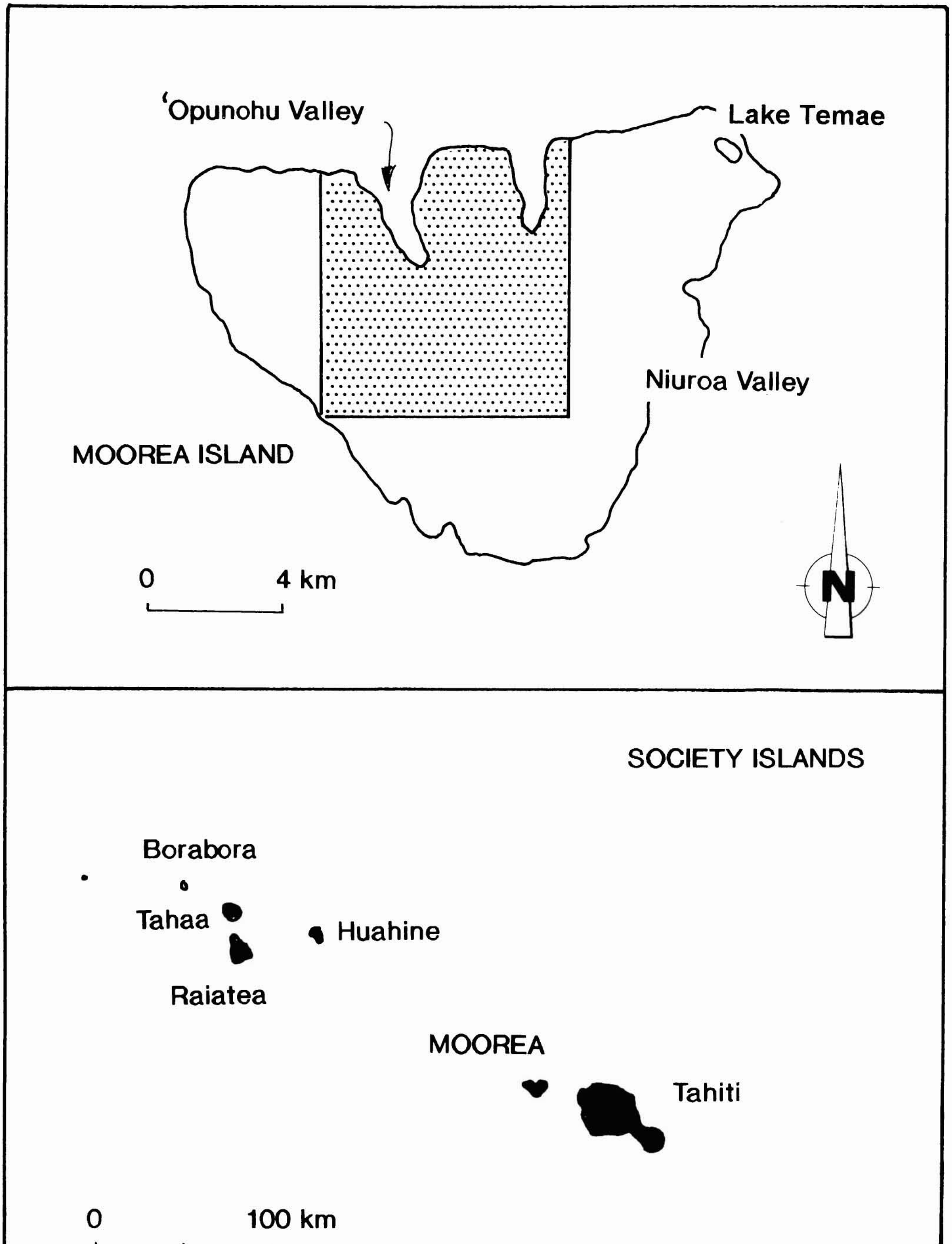

FIGURE 1. Maps showing the location of the study area. Bottom is the Society Islands showing the location of the island of Mo‘orea. Top shows the location of the ‘Opunohu Valley and other places on the island of Mo‘orea mentioned in the text. For details in the area of the shaded inset, see Figure 2.

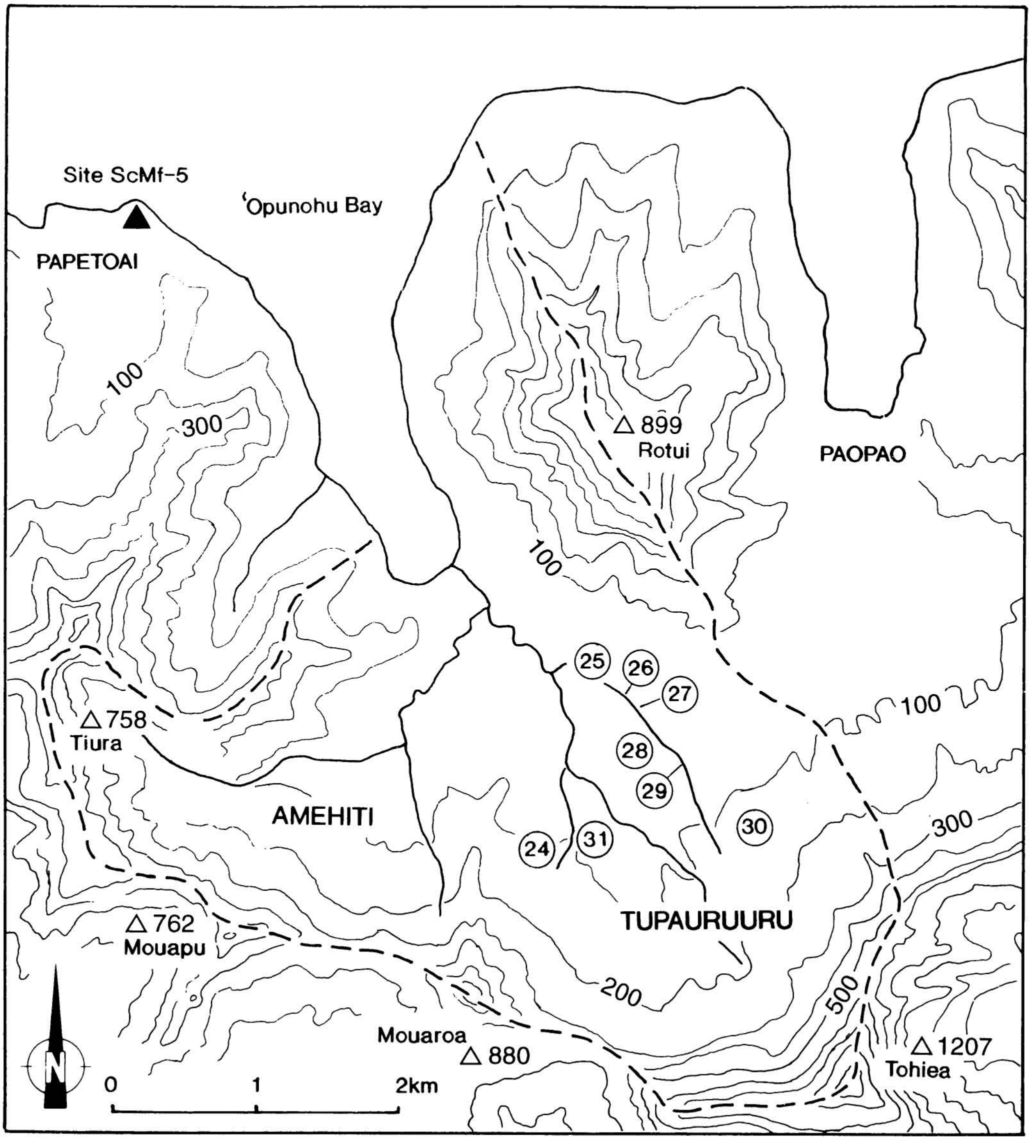

FIGURE 2. Topographic map of the 'Opunohu Valley showing location of stream profiles and excavation units in the upper valley.

cesses, is a key factor in reconstructing mid-to-late Holocene landscape change in the coastal zones of Pacific Islands. Throughout the central Pacific, a mid-Holocene high stand of ca. +1–1.5 m above the current sea level has been widely documented on a variety of geomorphological and archaeological evidence (Kirch 1993, Nunn 1994 : 279–297). In French Polynesia, sea level was 0.2–0.95 m above the current level 5000–1500 yr B.P. (Montaggioni and Pirazzoli 1984, Pirazzoli and Montaggioni 1985, Pirazzoli et al. 1987, 1988). Society Island relative sea levels have also been affected by local subsidence induced by crustal loading (Pirazzoli et al. 1985, Menard 1986). Direct archaeological evidence for subsidence at 'Opunohu was obtained by Rappaport and Rappaport (1967), who excavated a prehistoric oven (dated to 760 ± 80 yr B.P.) now submerged 0.25 m below mean sea level.

The timing of prehistoric Polynesian colonization of the Society Islands is currently a matter of considerable debate among archaeologists, part of a continuing controversy on the human settlement of East Polynesia (Irwin 1981, 1992, Kirch 1986, Sutton 1987, Spriggs and Anderson 1993). The oldest known habitation sites at Fa'ahia and Vaito'otia on Huahine Island date to ca. 1050–1150 yr B.P. (Sinoto and McCoy 1975), but there are good reasons to believe that these sites postdate the period of initial colonization (Kirch 1986). Recent paleoenvironmental evidence for Polynesian colonization of the southern Cook Islands by ca. 2500 yr B.P. (Ellison 1994, Kirch and Ellison 1994) raises the possibility that the Society Islands, only 500 km to the east, were also discovered and explored by the end of the first millennium B.C. Indeed, as Kirch and Ellison (1994) argued, paleoenvironmental evidence such as that presented in this paper may be more useful in determining the dates of initial human arrival in the Islands than traditional archaeological evidence derived from excavation of habitation sites.

The 'Opunohu Valley was selected as our research site in part because it has been the focus of considerable archaeological research, including an intensive surface survey of stone structural sites (Green 1961, Green et al. 1967, Green and Descantes 1989, Descantes 1990) and systematic excavations both in structures and coastal middens (Green et al. 1967). Those studies established that the valley had been a major locus of prehistoric human habitation and agricultural activities dating at least as far back as A.D. 1300.

MATERIALS AND METHODS

Stratigraphy

To expose stratigraphic profiles that would reveal geomorphic changes in the 'Opunohu Valley, 21 backhoe trenches (of ca. 4–5 by 2 m) were excavated throughout the valley floor (Excavation Units [EU] 1–21, Figure 3). Two stream-cut profiles were also examined in the lower valley (EU 22–23, Figure 3), and six stream profiles in the upper valley (EU 24–29, Figure 2). A single excavation unit was placed in the fern-covered knoll in the upper Tupauruuru side of 'Opunohu (EU 30, Figure 2). A 5-m road cut through a large fern patch in the upper valley was also examined (EU 31, Figure 2). After cleaning, the stratigraphic sections of all trenches and stream profiles were drawn to scale and characteristic lithology, color, and texture were recorded for the exposed strata. Sediment samples were taken from the cleaned facies and bagged for laboratory analysis. The sections were searched carefully for charcoal particles and, in the case of water-logged sediments, for anaerobically preserved plant remains, both of which were collected for radiocarbon dating and taxonomic identification.

Radiocarbon Dating

Reconstruction of the late Holocene sedimentary history of the 'Opunohu Valley necessitated accurate dating of the strata exposed in the trenches and profiles. Ten samples of charcoal collected from various test units were radiocarbon dated by accelerator mass spectrometry (AMS) at Lawrence Livermore National Laboratory, and two samples of anaerobically preserved coconut were dated by conventional radiocarbon method by Beta Analytic, Inc. All samples were pretreated for carbonates and humic acids using standard procedures, and the $^{13}C/^{12}C$ ratios were measured for all samples to establish ^{13}C adjusted, "conventional ^{14}C ages" following Stuiver and Polach (1977). Calibration of all ^{14}C ages for secular effects followed Stuiver and Becker (1993), and calibrations were made using Revision 3.0 of the CALIB FORTRAN microcomputer program of Stuiver and Reimer (1993). We used the *t*-test option in the CALIB program to determine statistical differences between radiocarbon age determinations. CALIB follows the statistical procedures of Ward and Wilson (1978). Additional

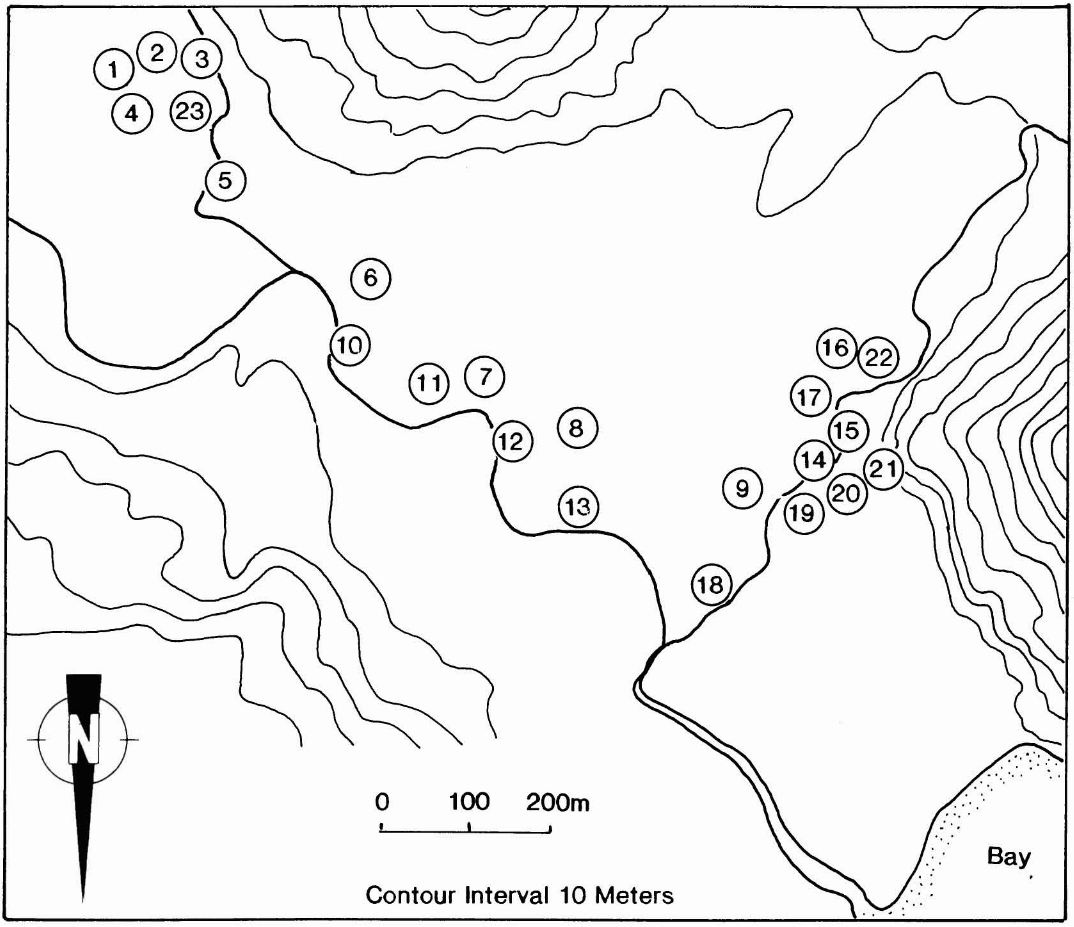

FIGURE 3. The 'Opunohu Valley floor showing location of valley floor excavation units and stream profiles.

series of ^{14}C from archaeological contexts throughout the valley are reported and discussed in Lepofsky (1995).

Sediment Analyses

Grain size analysis of wet-sieve categories of gravels ($> -1\ \phi$), sands ($0–4\ \phi$), and fines ($<4\ \phi$) was carried out on several sediment samples, and percentage of organic matter and of carbonates was determined by loss-on-ignition techniques (Dean 1974).

We also conducted X-ray diffraction (XRD) analysis (Carroll 1974) on seven sediment samples from the lower valley. By identifying the mineral content of sediments, XRD can be used to assess the weathering environment during soil development. Pedogenically young soils whose parent material was of mixed mineralogy are composed of a wide variety of minerals, whereas older, more weathered soils of the same origin are composed of fewer minerals. Similarly, the more easily weathered silt- and clay-size particles, such as amphibole and vermiculite, are characteristic of younger soils. Older soils are dominated by less easily weathered particles, such as kaolinite, and have little or no amphibole (Buol et al. 1973 : 81–83).

Paleobotanical Identifications

In addition to charcoal and wood from natural strata within the valley floor and upper valley excavation units, we collected charcoal from arbitrary levels or natural layers within the excavation units in five agricultural sites in the upper valley (O-159, O-267, O-262, O-286, O-27). Charcoal was cleaned and then identified by microscopy using standard techniques of "snap" transverse, tangential, and radial sections (Leney and Casteel 1975, Pearsall 1989). Sections of the unknown specimens were mounted for later examination. At least 10 charcoal specimens of 2 mm or larger were identified from each sample. A charcoal reference collection was used for identification of fossil charcoal.

RESULTS

The Lower Valley and Floodplain

The profiles from 11 of the 21 backhoe trenches and two stream cuts are schematically represented in Figure 4 and represent the stratigraphic variation observed across the valley floor. In general, the stratigraphy consists of four main facies groups: (1) basal deposits; (2) reduced deposits that are within and below the water table; (3) alluvial and colluvial facies; and (4) upper organically rich loams of alluvial origin. We discuss each facies group in turn below.

BASAL DEPOSITS. Because of the high water table, basal deposits were reached in only five of the excavation units, all of which are close to the base of the mountains. In two profiles (EU 1 and 2), the basal deposits are poorly

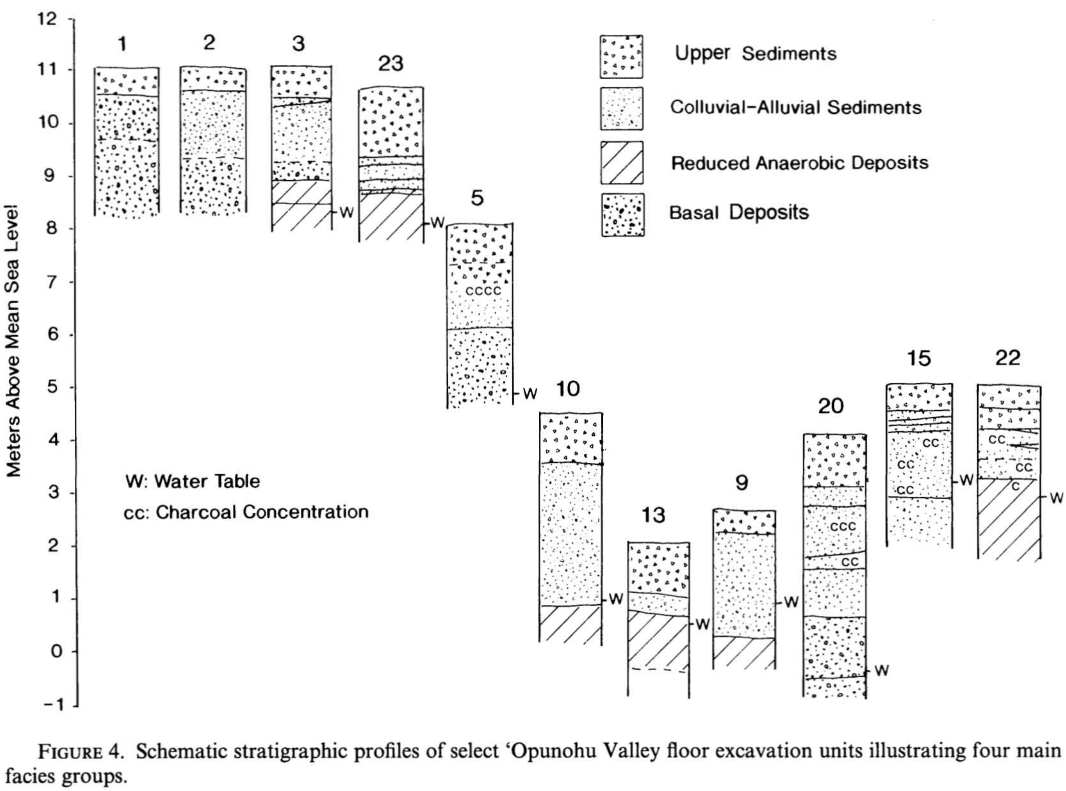

FIGURE 4. Schematic stratigraphic profiles of select 'Opunohu Valley floor excavation units illustrating four main facies groups.

sorted colluvial deposits, with increasingly large gravels found at increasing depth (Table 1). Degraded rocks are common throughout. These represent old colluvial deposits originating from the nearby slopes. In the other three units (EU 5, 20, and 21 [Figure 3]), the basal deposits are characterized by a hard, compact clay similar to the subsoil observed throughout much of the valley (e.g., EU 5, layer 5 [Table 1]).

TABLE 1

RESULTS OF SEDIMENT ANALYSES OF SELECT ‘OPUNOHU VALLEY FLOOR EXCAVATION UNITS

PROVENIENCE (UNIT/LAYER)	MUNSELL COLOR[a]	OM[b] (%)	CARBONATES (%)	CHARCOAL	GRAVELS (%)	SANDS (%)	FINES (%)	TEXTURAL CLASS[c]	INTERPRETATION[d]
EU 22/1	7.5YR 3/2	11.6	2.8	X	1.2	11.1	87.7	(g)sM	U
EU 22/2	7.5YR 3/2	13.1	3.0	X	0.3	17.7	82.0	sM	U
EU 22/3a	10YR 3/4	15.4	3.0	X	0.1	19.8	80.1	sM	A
EU 22/3b	10YR 3/4	13.5	3.2	X	0.1	20.1	79.8	sM	A
EU 22/5	10YR 3/3	15.3	3.2	X	0.0	20.1	79.9	sM	A
EU 22/6	7.5YR 3/3	15.6	2.9	X	0.3	39.2	60.5	sM	RA
EU 23/1	7.5YR 3/2	12.1	3.5	X	0.2	6.2	93.6	M	U
EU 23/2	7.5YR 3/2	12.1	3.8	X	0.7	14.3	85.0	sM	U
EU 23/3	7.5YR 3/2	10.9	3.8		7.1	23.0	69.9	gM	A
EU 23/5	7.5YR 4/6	10.3	4.1		3.6	15.1	81.3	(g)sM	A
EU 23/6	7.5YR 3/3	16.8	7.5		0.0	2.4	97.6	M	RA
EU 24/1	7.5YR 3/2	7.0	2.6		38.0	36.3	25.8	msG	B
EU 24/2	2.5YR 3/0	11.1	4.4		0.3	13.4	86.3	sM	B
EU 24/3	7.5YR 3/4	10.4	4.8		4.7	33.5	61.8	(g)sM	B
EU 1/2	7.5YR 3/2	5.2	1.6		20.7	64.0	15.3	gmS	B
EU 1/3	7.5YR 3/2	3.9	1.1		49.1	40.3	10.6	msG	B
EU 2/1	10YR 3/3	14.9	3.2		2.2	17.5	80.3	(g)sM	U
EU 2/2	7.5YR 3/4	11.9	4.4		0.5	41.4	58.1	sM	A
EU 2/3a	10YR 4/3	11.4	3.6		0.0	12.8	87.2	sM	A
EU 2/3b	10YR 4/3	6.8	2.6		32.2	42.1	25.7	msG	A
EU 2/4	7.5YR 3/4	7.4	2.7		3.7	61.0	35.3	(g)mS	A
EU 2/5	7.5YR 3/4	5.3	1.6		38.5	46.7	14.8	msG	B
EU 2/6	10YR 3/2	5.9	2.4		10.9	62.0	27.1	gmS	B
EU 3/2	10YR 3/3	9.9	3.6		1.7	39.0	59.3	(g)sM	A
EU 3/3	10YR 3/3	9.5	3.6		0.6	49.4	50.0	(g)sM	A
EU 3/4	7.5YR 4/4	7.8	2.5		19.5	19.5	61.0	gM	RA
EU 3/5	10YR 3/2	9.1	3.9		0.9	42.7	56.4	sM	RA
EU 3/6	7.5YR 3/0	8.1	3.6		5.8	51.0	43.2	gmS	RA
EU 5/1	7.5YR 3/4	25.1	3.3		0.4	5.9	93.7	M	U
EU 5/2	7.5YR 3/2	23.7	3.9	X	0.0	12.6	87.4	sM	U
EU 5/3	7.5YR 3/2	32.9	4.3	X	2.9	16.3	81.7	(g)sM	F
EU 5/4	7.5YR 3/4	27.5	4.2		0.2	20.0	79.8	(g)sM	A
EU 5/5	7.5YR 4/6	20.0	3.3		6.8	21.6	71.6	gM	B
EU 6/2	10YR 3/3	21.7	3.5	X	1.1	10.3	88.6	(g)sM	U
EU 7/2	10YR 3/2	22.0	3.6		0.0	26.7	70.0	sM	U
EU 7/3	10YR 3/3	20.9	3.6		3.3	16.8	82.3	(g)sM	A
EU 7/4	7.5YR 3/3	21.7	3.5		0.9	10.3	88.6	sM	A
EU 8/3	7.5YR 3/2	11.0	3.8	X	0.0	9.3	90.7	M	U
EU 9/1	7.5YR 3/2	14.6	2.7	X	4.0	15.6	80.4	(g)sM	U
EU 9/2	7.5YR 3/2	10.3	3.2	X	1.6	12.7	85.7	(g)sM	U
EU 9/4	7.5YR 3/3	13.7	3.2		3.1	30.0	66.9	(g)sM	RA

[a] Moist.
[b] Organic matter.
[c] After Folk (1974).
[d] U, upper sediments; A, alluvial and colluvial sediments; F, feature; RA, reduced anaerobic deposits; B, basal deposits.

REDUCED DEPOSITS. The water table was reached in most trenches on the valley floor (Figure 4), limiting excavations. The water table corresponds with the top of the reduced deposits. These deposits range from very fine-grained (e.g., EU 23, layer 6 [Table 1]) to somewhat coarser deposits (e.g., EU 3, layers 5 and 6; EU 22, layer 6 [Table 1]). A considerably coarser-grained reduced fluvial deposit was found in a few trenches as well (e.g., EU 15 [Figure 4]). The results of the XRD analysis of the sediments from EU 23 reveal that the clays are primarily kaolinite, indicating a highly weathered environment characteristic of a surface soil (Table 2).

With the exception of the coarsest-grained stream deposits, most of the reduced layers contain anaerobically preserved coconut roots and wood from *Hibiscus tiliaceus* and *Barringtonia asiatica* (L.) Kurz trees (Table 3). In the case of EU 23, this layer also contained occasional *Aleurites moluccana* and *Cerbera manghas* L. seed endocarps, and several coconuts (*Cocos nucifera* L.) that are preserved in their entirety except for the endosperm. The coconuts were identified as an early cultivated form intermediate between the true wild and domesticated forms. The deposition of the coconuts in nonmarine sediments, considerably above sea level, indicates that the nuts originated from trees that were deliberately planted in the 'Opunohu Valley (Lepofsky et al. 1992). Two coconuts from this layer were radiocarbon dated between A.D. 654 and 936 (Table 4).

We infer that the reduced sediments were deposited between the seventh and tenth centuries at a time when the valley floor was intertidal marshes resulting from a fall in relative sea level of ca. 0.9 m before 1500 yr B.P. (Montaggioni and Pirazzoli 1984, Pirazzoli and Montaggioni 1985, Pirazzoli et al. 1987, 1988). With the exception of the coarsest fluvially deposited sediments, the grain size of the reduced deposits indicates a low to moderate energy depositional environment. This suggests that the valley floor was swampy, with higher energy streams running through it, probably in a braided pattern. The presence of preserved plant remains within these sediments indicates that the deposits have been waterlogged since the time of deposition. The floral remains suggest that the valley floor supported a mixture of strand line and forest vegetation, as well as cultivated coconuts.

The combined results of the XRD and sediment analyses indicate that the 'Opunohu uplands were relatively stable during the time the coconuts were cultivated in the lower valley. During that time there was little in situ soil formation or weathering in the swampy

TABLE 2

DESCRIPTIVE RESULTS OF X-RAY DEFRACTION (XRD) ANALYSIS OF 'OPUNOHU VALLEY FLOOR SEDIMENTS

PROVENIENCE (UNIT/LAYER)	DESCRIPTION	INTERPRETATION[a]
EU 23/3	Kaolinite dominant, trace amphibole, possibly some vermiculite	Somewhat weathered, laterite; subsoil
EU 23/6	Kaolinite dominant, no amphibole	Periods of desiccation, good drainage, highly weathered; typical of surface soil
EU 3/4	Possibly some kaolinite and vermiculite, possibly volcanic ash, amorphous	Not free drainage when formed, never a surface; volcanic bedrock
EU 5/1	Kaolinite dominant, no amphibole	Periods of desiccation, good drainage, highly weathered; typical of surface soil
EU 5/4	Kaolinite dominant, possibly amphibole	Periods of desiccation, good drainage, some weathering; never a surface
EU 7/2	Kaolinite dominant, trace amphibole, possibly some vermiculite	Somewhat weathered, laterite; subsoil
EU 7/3	Kaolinite, vermiculite	Some weathering; not a surface soil

[a] See Table 1 for interpretation of depositional environment.

TABLE 3

CHARCOAL AND WOOD IDENTIFICATIONS[a] FROM 'OPUNOHU VALLEY FLOOR EXCAVATION UNITS

		POLYNESIAN INTRODUCTIONS			INDIGENOUS					OTHER		
PROVENIENCE (UNIT/LAYER)	n	Coco	Ino	Aleu	Hib	Barr	F.ber	F.tin	Thes	Mono	Exo	Unid
EU 5/2	10		2		5							3
EU 5/3	5											5
EU 6/2	1									1		
EU 7/1	1											1
EU 7/4	1				1							
EU 8/2	2										1	1
EU 8/3	4		1		1			1?				1
EU 8/7b[b]	2	1				1						
EU 9/2	2				1							1
EU 9/4[b]	2						1?					1
EU 11/2	10				2				3	1		4
EU 13/1	2				2							
EU 13/3[b]	2	1					1?					
EU 14/2	2				1		1?					
EU 14/3	4			1[c]	2							1
EU 14/4	1	1[d]										
EU 15/5	35		15		14				4			2
EU 16/2	9				2							7
EU 20/3	5								4			1
EU 22/2	3										3	
EU 22/3	3			1[c]								2
EU 22/5	2				2							
EU 22/6/7	5											5

[a] Species abbreviations: Aleu, *Aleurites moluccana*; Barr, *Barringtonia asiatica*; Coco, *Cocos nucifera*; F.ber, *Fragraea berteroana*; F.tin, *Ficus tinctoria*; Hib, *Hibiscus tiliaceus*; Ino, *Inocarpus fagifer*; Thes, *Thespesia populnea*; Mono, unidentified monocot; Exo, unidentified exocarp; Unid, unidentified species; all specimens are charcoal unless otherwise indicated.
[b] Uncharred specimens.
[c] Exocarp.
[d] Root.

lower valley, and weathered sediments in the reduced deposits there originated from surface soils in the upper valley. The fine grain size indicates that those upper valley sediments were washed slowly onto the valley floor from the hill slopes above. From this low rate of sediment transport, we expect that the primary forest of the upper slopes was not subject to major disturbances during that time. Thus, with the exception of the cultivation of coconuts on the swampy valley floor, human modification to the 'Opunohu Valley during the seventh to tenth centuries A.D. appears to have been minimal.

COLLUVIAL AND ALLUVIAL SEDIMENTS. Above the inundated layers, the lower valley profiles are characterized by either alluvial or colluvial deposits (Figure 4). The distinction between alluvium and colluvium is somewhat arbitrary, because all the sediments in the lower valley ultimately derive from the surrounding mountains, and the streams play a major role in their transport and deposition. The deposition of these colluvial and alluvial sediments onto the swampy terrain eventually transformed the valley floor into a drier alluvial flat.

The colluvial deposits are relatively homogeneous in internal structure and are composed of poorly sorted, subangular sediments. These sediments derived from mass wasting events on the surrounding slopes and were spread onto the valley floor in major flood

TABLE 4

RADIOCARBON DATES FROM 'OPUNOHU VALLEY EXCAVATION UNITS

LABORATORY NO.	DESCRIPTION[a]	$\delta^{13}C$	CONVENTIONAL ^{14}C AGE B.P.	CALIBRATED AGE RANGE(S)[b]
CAMS 6250	EU 22/1; charcoal	−27.6	>modern	—
CAMS 6251	EU 22/3b; charcoal	−22.8	970 ± 90	A.D. 1003–1008, 1018–1216
CAMS 6254	EU 22/7, uncharred wood	−27.8	160 ± 60	A.D. 1676–1776, 1803–1940, 1954–1955
CAMS 6252	EU 5/3; charcoal	−27.9	920 ± 60	A.D. 1043–1090, 1118–1139, 1150–1222, 1232–1239, 1249–1256
CAMS 6253	EU 20/6b; coconut root	−26.5	150 ± 70	A.D. 1676–1776, 1803–1940, 1954–1955
CAMS 6255	EU 23/2; charcoal	−26.4	720 ± 60	A.D. 1281–1327, 1350–1364, 1365–1390
BETA 41159	EU 23/7; coconut husk	−28.5	1,270 ± 60	A.D. 691–703, 708–750, 764–888, 932–936
BETA 41160	EU 23/6b; coconut husk	−25.4	1,360 ± 60	A.D. 654–775
CAMS 6256	EU 25/3; charcoal	−25.3	710 ± 60	A.D. 1283–1329, 1348–1392
CAMS 6259	EU 25/3; charcoal	−30.2	600 ± 60	A.D. 1325–1352, 1360–1366, 1388–1430
CAMS 6257	EU 26/2; charcoal	−26.4	350 ± 60	A.D. 1491–1604, 1609–1656
CAMS 6258	EU 26/5; charcoal	−25.8	560 ± 60	A.D. 1333–1339, 1398–1440

[a] Excavation unit number/layer number.

[b] At 1 sigma, using CALIB program, method A (Stuiver and Reimer 1993) with decadal calibration scale (Stuiver and Becker 1993), and subtracting 40 yr from ^{14}C age for southern hemisphere dates (Stuiver and Reimer 1993).

events. The large amounts of sediments in these early deposits are related to some kind of upslope disturbance. The colluvial deposits range from coarser-grained sediments in the three colluvial layers of EU 3 (Table 1) to finer-grained sediments in the other units (e.g., EU 23, layers 3 and 5; EU 5, layer 4; EU 7, layers 3 and 4). The coarser-grained sediments in EU 3 are probably a result of its proximity to the base of the mountain. Only the colluvial deposits of EU 22 contained charcoal (*Hibiscus tiliaceus*, an unidentified hard endocarp, and several other unidentified wood species [Table 3]). The results of the XRD analyses from EU 23, 5, and 7 indicate that, though the colluvial deposits display some weathering, none were exposed long enough to be considered a surface soil, either in their source locations or after deposition on the valley floor (Table 2). We infer from this that these sediments were displaced from their source locations on the upper slopes by disturbance events large enough not only to rapidly expose and mobilize subsurface material, but to bury it again on the valley floor before it was exposed to appreciable weathering.

The alluvial layers are composed of homogeneous lenses dominated by either clay, silt, sand, or gravel (Table 1), often interfingered in a classic fluvial depositional sequence. They represent more localized fluvial events than the colluvial deposits already discussed. The alluvial layers either are interspersed between the colluvial deposits (e.g., EU 3 and 23 [Figure 4]) or entirely dominate the stratigraphy (e.g., EU 9, 10, 15, 20, and 22 [Figure 4]). Charcoal fragments were found within some of the clay, silt, and fine sand layers, especially in the profiles along the northwest of the valley floor. A charcoal-bearing clay lens in EU 22, previously interpreted as a possible paleosol (Lepofsky et al. 1992), is now thought to have been deposited in low-energy stream pools similar to those found in the protected bends of the modern streams. Charcoal from a clay layer in EU 22 was radiocarbon dated at A.D. 1003–1216 (Table 4).

A distinct charcoal lens about 1 m below the current ground surface was discovered above a colluvial deposit in EU 5 (Figure 4). Fire reddening associated with the base of the layer and occasional fire-altered rocks suggest that it was a cultural feature. This feature provides the most direct evidence for human use of the valley floor and was radiocarbon dated at A.D. 1043–1256 (Table 4). Unfortunately, none of the charcoal associated with the feature could be identified.

We interpret the disturbance associated with the charcoal in the alluvial and colluvial deposits as human-induced, rather than from natural causes. This interpretation is consistent with the fact that natural fires play a minor role in rain forests in general (Uhl et al. 1988, Uhl and Kauffman 1990, Hopkins et al. 1993) and in Pacific Islands rain forests in particular (Kirch and Ellison 1994). The presence of "substantial and sustained quantities of charcoal particles" in our deposits (Kirch and Ellison 1994: 312), coincident with a cultural feature, provide strong support for human-set fires in the 'Opunohu Valley.

The charcoal lens and the charcoal found in the alluvial deposits indicate widespread human use of the valley floor between the eleventh and thirteenth centuries after it had been considerably transformed by the deposition of large amounts of colluvium and alluvium. The radiocarbon dates from the clay layer in EU 22, in the extreme northwest corner of the valley floor, and from the charcoal lens from EU 5, at the southern end of the valley floor, cannot be distinguished statistically ($\alpha = 0.05$, t-test), suggesting that, at that time, much of the valley floor was being used.

The charcoal identifications from the alluvial and colluvial layers indicate a mixture of strand and forest vegetation similar to that found in the older, reduced deposits. Although the majority of the charcoal occurs in the fluvial deposits, these were low-energy depositional environments, suggesting that the charcoal was not transported far from its source. The presence of *Hibiscus tiliaceus*, *Aleurites moluccana*, and *Inocarpus fagifer* (Table 3) is important in indicating anthropogenic modifications to the valley floor environment. Two of these taxa are Polynesian introductions, and *Hibiscus* is known to thrive in anthropogenically disturbed habitats and may have been an aboriginal introduction (Whistler 1991).

UPPER SEDIMENTS. The upper 0.5 to 1.5 m of each profile is characterized by a dark brown (Munsell color 10 YR 3/3) organically rich loam. These deposits are relatively homogeneous, lacking internal structure. Some of these deposits contain charcoal flecking. The presence of charcoal flecking is not associated with grain size, however, indicating similar depositional environments (Table 1). Taxa identified from charcoal in these sediments were *Hibiscus tiliaceus*, *Inocarpus fagifer*, *Thespesia populnea* (Soland ex.) Parkins, and possibly *Ficus tinctoria* Forst. f., in addition to an unidentified monocot and several other unidentified species (Table 3). XRD analyses of sediments sampled at 1.5 m below the surface of EU 7 indicate a somewhat weathered, lateritic subsoil (Table 2). Not surprisingly, XRD results from sediments from 30 cm below the surface of EU 5 are typical of a surface soil (Table 2). A charcoal lens located 40 cm below the ground surface of EU 22 was radiocarbon dated as modern (i.e., after 1950 [Table 4]).

These upper deposits suggest a recent continuation of the colluvial-alluvial depositional sequence described above. The modern date on the charcoal lens from EU 22 indicates that similar depositional processes continue today.

The vegetation identified from charcoal in the upper sediments is similar to that of the underlying alluvial and colluvial units—a combination of strand and forest vegetation. The presence of charcoal flecking throughout the upper deposits suggests direct human use of the valley floor, possibly from burning events associated with clearing for gardening.

The Upper Valley

STREAM PROFILES. EU 24, located on the main Tupauruuru stream, is characterized by three distinct colluvial layers. The upper and lowermost layers are quite coarse, but the middle layer is a fine, homogeneous oxidized deposit (Table 1) similar to the basal deposit described for EU 5, 20, and 21 in the lower valley. No charcoal or other cultural materials were recovered from the profile; it is likely that these deposits are of considerable age and predate human occupation.

EU 25–29, located on two different tributaries along the eastern edge of Tupauruuru, display a quite different stratigraphy from EU 24 located on the main Tupauruuru stream. Each profile was cleared until basal deposits or the stream level was reached. Basal deposits underlying EU 26–29 are composed of compact oxidized or reduced silty clays, similar to the middle layer of EU 24. Coarser colluvial deposits, similar to the lowermost layer in EU 24, are also found in EU 26. In EU 26, 27, and 29, the basal deposits are overlain by a homogeneous oxidized or reduced clay layer, ranging from 20 to 35 cm thick and containing charcoal flecking throughout. A charcoal specimen from this layer in EU 26 yielded a radiocarbon date of A.D. 1333–1440 (Table 4). In EU 25, the clay layer is considerably thicker, beginning ca. 70 cm below the ground surface and continuing to below the current stream level. This layer is reduced and, thus, in addition to charcoal, contains anaerobically preserved roots (unidentified). The charcoal specimens were identified as charred *Aleurites moluccana* endocarps, *Hibiscus tiliaceus*, and *Inocarpus fagifer* (Table 5). Two charcoal specimens from about 1 m below the surface in this layer were radiocarbon dated at A.D. 1352–1430 and 1283–1392 (Table 4). The two dates cannot be statistically distinguished ($\alpha = 0.05$, t-test), suggesting that the charcoal may have come from the same depositional event.

Alluvial deposits are above these clay layers in EU 25, 28, and 29. These alluvial deposits are characterized by a fingering of lenses of oxidized gravels and sands with reduced clays, similar to those found in several valley floor trenches. As in the valley floor profiles, the clay layers in these upper valley stream profiles contain charcoal fragments.

TABLE 5

CHARCOAL IDENTIFICATIONS[a] FROM 'OPUNOHU UPPER VALLEY EXCAVATION UNITS

PROVENIENCE		POLYNESIAN INTRODUCTIONS						INDIGENOUS			OTHER		
(UNIT/LAYER)	*n*	Arto	Cord	Coco	Ino	Syzy	Aleu	Hib	F.pro	F.tin	Mono	Endo	Unid
EU 22/1	10												10
EU 22/3	6						1[b]	3					2
EU 26/4	10							10					
EU 27/2	10				3			7					
EU 29/2	4							3					1
O-159, EU 2/2	8												8
O-159, EU 3/1	10								10?				
O-159, EU 3/2	47				4			14	3	6?	1	6	13
O-159, EU 3/4	15	1			1			5					8
O-267, EU 7/3	63			1				48				1	13
O-267, EU 7/4	10							4					6
O-262, EU 11/2	10	2?						6					2
O-286, EU 3/2	23	1					2	5				2	13
O-286, EU 3/3	30	1				3		17					9
O-286, EU 3/4	7		6										1
O-286, EU 4/2	20						12						8
O-27, EU 16/2	33				2	8	8	4					11

[a] Species abbreviations: Aleu, *Aleurites moluccana*; Arto, *Artocarpus altilis*; Coco, *Cocos nucifera*; Cord, *Cordyline fruticosa*; F.pro, *Ficus prolixa*; F.tin, *Ficus tinctoria*; Hib, *Hibiscus tiliaceus*; Ino, *Inocarpus fagifer*; Syzy, *Syzygium malaccense*; Mono, unidentified monocot; Endo, unidentified endocarp; Unid, unidentified species.

[b] Endocarp.

One such fragment from 40 cm below the surface of EU 26 was radiocarbon dated at A.D. 1491–1656 (Table 4).

The surface layers of EU 26 and 27 are coarse-grained colluvium. The surface deposits in EU 28 and 29 are a dark brown loam similar to that found on the surface of the valley floor trenches. A charcoal lens underlies this layer in EU 28, and charcoal flecks are contained within this layer. Because of the proximity of EU 28 and 29 to the edge of a modern pineapple plantation, these upper loamy layers may be modern.

In general, the upper valley stratigraphic profiles indicate relatively low-energy depositional environments dominated by a fluvial mode of deposition. However, the colluvium in profiles EU 26 and 27 indicates that low-energy deposition in the past was followed by a considerably higher-energy mass wasting event. The age of the colluvial deposition remains undetermined, but the radiocarbon dates indicate that a low-energy environment dominated from at least the thirteenth century A.D. to the mid-seventeenth century. Because of the characteristic low-energy depositional environment, charcoal must have originated from the immediate surrounding vegetation. Based on the charcoal identifications, this vegetation was characterized by a mixture of early successional and adventive species (Table 5), similar to that found in the 'Opunohu Valley today.

The sedimentation sequence revealed in the upper valley stream profiles, combined with the presence of charcoal, suggests localized erosion caused by vegetation clearing, probably for agricultural purposes. The radiocarbon dates suggest that this clearing occurred at least as early as the thirteenth century and continued almost until the time of European contact. The presence of early successional vegetation in the earliest dated layers indicates that the forest had already been transformed by human activities by the thirteenth century.

The contrast between EU 24 on the main Tupauruuru stream and EU 25–29 is striking. There is a complete absence of cultural remains in EU 24, despite the fact that it is located adjacent to one of the densest archaeological settlements in the valley. This contrasts with EU 25–29, almost all of which contain charcoal, which are located in an area of considerably lower site density. The lack of charcoal in the former may be explained by its proximity to the main stream channel, which could have been too high an energy environment for consistent charcoal deposition. The smaller, slower-moving eastern tributaries were more likely to deposit charcoal. The charcoal may have originated from localized clearing for agriculture that left no other archaeological traces.

FERNLANDS. Exploration of the fern-covered knolls revealed a relatively simple stratigraphy. In both the road cut profile and the test pit in the *Dicranopteris* fern-covered knoll (EU 30 and 31), the profiles are dominated by a compact lateritic clay with occasional subrounded or subangular cobbles. The compact clay layer is the same as the basal deposits of EU 5, 20, 21, 26–29, and layer 2 of EU 24. In both profiles there is no development of deep, weathered soil. In the test pit in the fern-covered knoll, there is a thin layer of charred *Dicranopteris* fern stems below the surface. The charred stems may have resulted from modern hunting episodes, when fern patches are burned to flush pigs (M. Kellum, pers. comm., 1992).

AGRICULTURAL SITES. Identified charcoal specimens from five prehistoric agricultural sites in the upper 'Opunohu are dominated by early successional forest species and by Polynesian cultigens (Table 5). Although 33% of the charcoal specimens could not be identified, *Hibiscus tiliaceus*, which thrives in disturbed soils, composes 37% of the total assemblage. Polynesian cultigens, comprising breadfruit (*Artocarpus altilis* [Parkins. ex Z] Fosb.), coconut (*Cocos nucifera*), Malay apple (*Syzygium malaccense*), ti (*Cordyline fruticosa* [L.] A. Chev.), and Tahitian chestnut (*Inocarpus fagifer*), make up 11% of the 'Opunohu assemblage. Candlenut (*Aleurites moluccana*), which may have been a Polynesian introduction, composes 8% of the assemblage. The remaining 11% of the upper

‘Opunohu assemblage is composed of *Ficus* spp., an unidentified monocot, and the hard exocarp of an unidentified nut (Table 5).

The charcoal occurring in the agricultural sites presumably originated from fires set some time before the construction of the agricultural terraces. Based on the stratigraphic evidence revealed during excavations (Lepofsky 1994, chapter 4), the charcoal probably resulted from vegetation clearing that directly preceded terrace construction. After each burn event, the charcoal would have been incorporated into the agricultural deposits during terrace construction and/or use. Thus, the charcoal found in the agricultural deposits represents the vegetation growing immediately before terraced agriculture in that location. In the few sites with multiple agricultural layers, the charcoal found in the upper layers probably originated from burning successional vegetation growing on the terrace between planting events.

The identified charcoal from the upper valley agricultural sites indicates a forest composition similar to that extant today in nearby forests. *Hibiscus tiliaceus* dominates both the modern vegetation and that represented by the charcoal, with other early successional and cultivated species making up a minor component of both the modern and the prehistoric vegetation. A notable difference between the modern and the prehistoric vegetation is the poor representation of *Inocarpus fagifer* charcoal (2.5% of the total charcoal assemblage). This may suggest that in the past *Inocarpus* was more limited to garden plots and that the modern dominance of *Inocarpus* resulted from the self-dispersal of feral trees after the valley was less intensively cultivated. A similar inventory of charcoal was recovered from agricultural sites in the Niuroa Valley (Figure 1; Lepofsky 1994, appendix 4).

DISCUSSION

The excavation units and the stream profiles reveal a long history of human interaction with the ‘Opunohu landscape, which we have diagrammatically summarized in Figure 5. Before human colonization of ‘Opunohu, the valley floor was submerged because of a sea level stand roughly 1 m higher than current (Figure 5*a*). By at least the seventh century A.D., humans had commenced using the ‘Opunohu Valley floor for coconut cultivation, but did not substantially modify the upper valley (Figure 5*b*). The waterlogged, fine black matrix in which the coconuts and other anaerobically preserved plant remains were deposited suggests that at cal A.D. 600 the ‘Opunohu lower valley was a swamp. The floral remains, with their mixture of native strand and forest vegetation, suggest that human use of the valley floor was relatively nonintensive at that time. There is no evidence other than the coconuts for early human use of the ‘Opunohu Valley. However, because such early sites would be few and as deeply buried as the coconuts, the chances of discovering them are slim.

Changes in relative sea level also complicate the problem of locating earlier evidence of human use of ‘Opunohu. Although sea level had reached its current level by the time the coconuts were being cultivated in the lower ‘Opunohu Valley, continued subsidence of Mo‘orea (Pirazzoli et al. 1985) may have resulted in submergence of early coastal sites. Indeed, the bottom 30 cm of an earth oven at the coastal site of ScMf-5 (Figure 2) (Rappaport and Rappaport 1967) is below the current water table. This feature only dates between the thirteenth and fourteenth centuries; earlier coastal sites are likely completely submerged (Kirch 1986).

Some time after cal A.D. 600, disturbance upslope resulted in an influx of 1–2 m of sediment to the valley floor (Figure 5*c*), giving a total volume over the 800-ha floodplain of 8–16 $\times 10^6$ m^3 for this influx. The depleted lateritic soils in the upper valley are the result of that erosion.

We posit that the upslope disturbance that initiated this influx was the clearing of primary forest by humans for agricultural purposes. The hypothesis of human-induced disturbance accounts for both the presence of charcoal within the sediments and the wide-

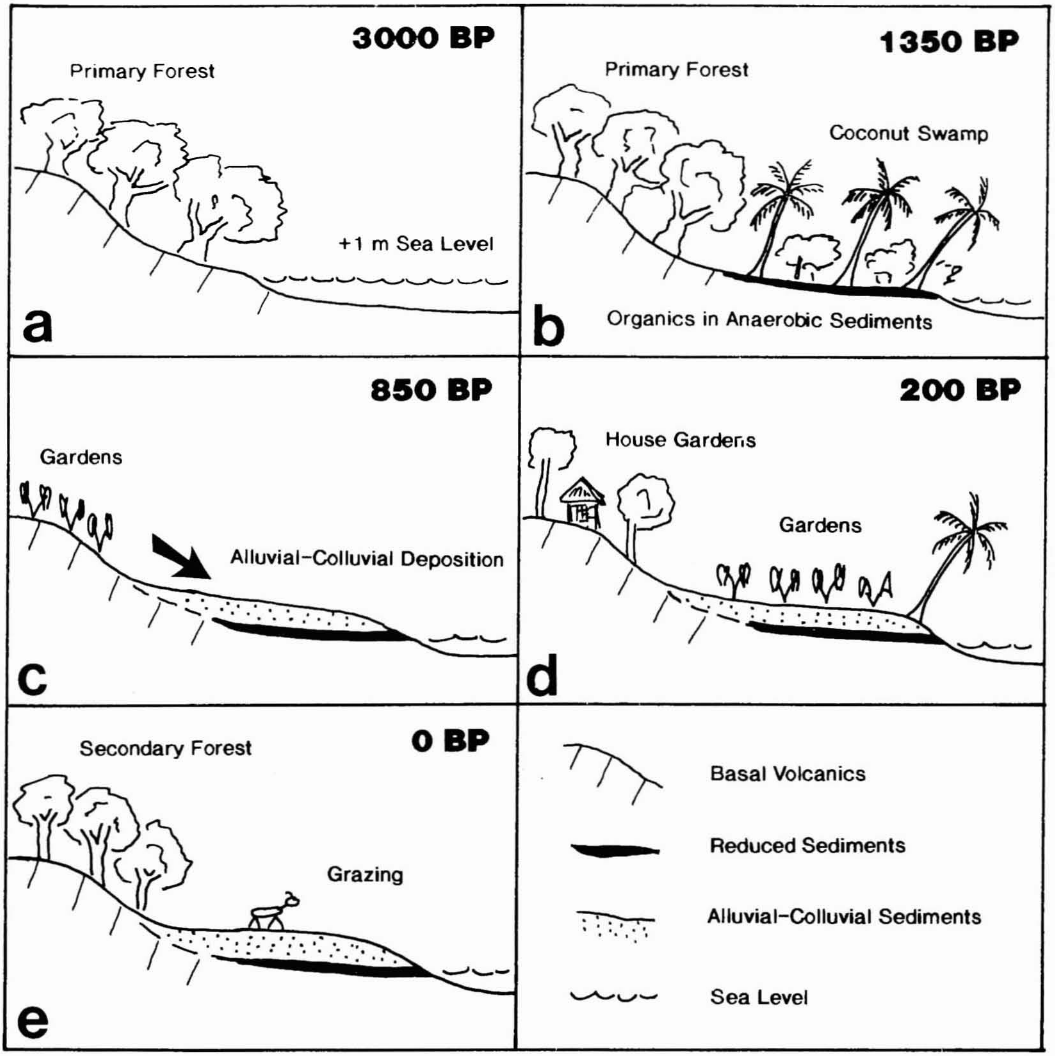

FIGURE 5. Sequence of human-induced landscape change and use in the 'Opunohu Valley. See text for explanation.

spread, intense disturbance over the landscape. Although cyclones can also cause substantial disturbance to tropical forests (e.g., Shaw 1983), wind disturbance to forests is not commonly associated with extensive mass wasting. Furthermore, intense disturbance by wind is generally restricted to exposed patches in forested landscapes, and, in mountainous terrain, much of the disturbed area is likely to experience only moderate levels of disturbance (Boose et al. 1994). Humans are the most likely agents for the widespread and intense environmental change that must have occurred in 'Opunohu to produce the geomorphic changes we observed. Similar processes of human-induced landscape change have been documented for other Pacific Islands (Hughes et al 1979, Allen-Wheeler 1981, Spriggs 1981, 1985, McGlone 1983, 1989, Kirch 1984, 1994).

We conclude that by the time the agricultural terraces were built in the upper 'Opunohu Valley, vegetation had already been substantially altered by human activity. The presence of cultigens suggests that the vegetation on the upper valley slopes was composed of a mixture of early successional species and assorted cultigens. This is consistent with the vegetation characteristic of mixed swidden gardens. Notably, charcoal from those cultigens was only recovered from the deepest (i.e., earliest) layers in units with more than one cultural layer. This may suggest that mixed swidden crops were no longer planted after a hillside was converted to terraced agricultural plots. If, as we propose, the charcoal from the upper cultural layers represents the early successional vegetation growing on the terrace between planting events (Lepofsky 1994), the presence of tree and shrub charcoal further indicates relatively long fallow periods between planting events.

Recent pollen evidence from Lake Vaihiria on Tahiti and Lake Temae on Mo'orea (Figure 1) supports our reconstruction of early human modifications of the 'Opunohu landscape (Parkes and Flenley 1990). Beginning cal A.D. 658–977 in Vaihiria and cal A.D. 428–651 in Temae, there is evidence for upland soil erosion and deposition downslope. This was accompanied by the loss of some primary forest species and the establishment of *Dicranopteris* fernlands. In both sequences, initial disturbances were small-scale. Based on the high amounts of calcareous sediment, Parkes and Flenley (1990) attributed the earliest disturbances at Vaihiria to cyclonic rather than to human disturbance. However, an alternative hypothesis is that the human input to these early disturbances was small-scale, with a more major input from climate. Parkes and Flenley interpreted the presence of coconut pollen in those earliest levels as wild stands of coconut, but it could have originated from early cultivated trees as in the 'Opunohu case. After the initial small-scale disturbances, both pollen sequences exhibit a period of more extensive disturbance. The period of greatest disturbance has been dated at Temae to cal A.D. 774–987. The evidence for disturbance during that period includes high levels of charcoal, which was attributed to deforestation through human-induced burning of the upper slopes (Parkes and Flenley 1990). An age after cal A.D. 600 for extensive disturbance in both lake sequences corresponds well to the period of initial extensive disturbance postulated for the 'Opunohu sequence.

In 'Opunohu, there is no direct evidence for human use of the newly created drier alluvial flat in the valley floor until cal A.D. 1000–1100 (Figure 5*d*). Human use at that point is indicated by the hearth feature and by the deposition of charcoal in low-energy stream pools, dating between cal A.D. 1000 and 1200. The charcoal-bearing deposits in the upper 1 m of several of the test pits suggest that sometime after cal A.D. 1000–1200 the 'Opunohu Valley inhabitants began to use the infilled valley floor more intensively, possibly for agriculture. If the valley floor was in fact used for agriculture, the presence of tree species in the charcoal may indicate a relatively long fallow period between plantings.

None of our radiocarbon samples from the valley date to after cal A.D. 1000–1200, but dates from archaeological sites in other parts of 'Opunohu suggest that use of the valley was widespread at that time. Sites OPU-4 in Amehiti (Green and Green 1967), OPU-159 in upper Tupauruuru (Lepofsky 1994, table 4.1), and ScMf-5 on the 'Opunohu coast (Rappaport and Rappaport 1967) all date between cal A.D. 1200 and 1300. The evidence for agricultural clearing associated with charcoal in the upper valley stream profiles further supports increased human use of the valley beginning at that time. We posit that use of the lower valley for agricultural production also began during that period. However, the fact that early successional vegetation was well established in the upper valley by that time, as indicated both by the stream profiles and the charcoal recovered from the agricultural sites, supports the notion that humans had already substantially altered the upper valley forest before cal A.D. 1200. Radiocarbon dates from the upper valley stream profiles, and early European drawings and accounts (Lepofsky 1994, chapter 2) indicate that vegetation clearing, likely for agriculture, continued in 'Opunohu until the time of European contact. Based on ethnohistoric accounts (Green 1967), we can conclude that the lower valley ceased to be cultivated sometime before A.D. 1805. The modern date from 40 cm below the current valley floor surface is associated with modern upslope disturbance in the form of clearing for the extensive pineapple plantations located in the upper valley.

CONCLUSIONS

Human actions played an important role in transforming the landscape of the 'Opunohu Valley during the late Holocene. Polynesian settlers were present in the valley by at least cal A.D. 600, based on the evidence of cultivated coconuts, even though habitation sites have yet to be discovered. Upslope clearing beginning sometime after cal A.D. 600, probably for agriculture, resulted in a massive sediment influx to the floodplain and consequent transformation of the valley floor from a swamp to a relatively dry alluvial flat by about cal A.D. 1000. As a result, parts of the upper valley now covered in *Dicranopteris* fernland became denuded and sufficiently laterized that they could no longer support cultivation or vegetation other than the pyrophytic ferns.

In addition to these geomorphic changes, the Polynesian inhabitants of 'Opunohu were responsible for the introduction of several tree species that now dominate the valley's forest cover. Such cultivated tree crops as *Inocarpus fagifer*, *Syzygium malaccense*, and *Artocarpus altilis*, along with the economically useful introduction *Aleurites moluccana*, were all well established by cal A.D. 1200–1300. After that date the vegetation present throughout both the upper valley and the floodplain was strongly anthropogenic, dominated by these Polynesian introductions along with early successional species such as *Hibiscus tiliaceus*.

Human-induced modifications to the prehistoric landscape also have important implications for interpreting the archaeological record of Mo'orea and the Society Islands. In 'Opunohu Valley, the earliest archaeological sites with visible surface remains date to ca. A.D. 1200, and the cultivated coconuts, which are overlain by almost 2 m of sediment, date to ca. A.D. 650 (Lepofsky et al. 1992). Moreover, because we were unable to reach the base of the waterlogged deposits, the A.D. 650 date should not necessarily be taken as evidence of *initial* human settlement in the valley. The 'Opunohu stratigraphic sequence thus provides a cautionary lesson that early sites in the Society Islands are likely to be deeply buried under alluvial and colluvial sediments. Further, archaeological remains visible on modern landscapes are likely to date only to the more recent periods of human occupation. This forces a broad reconsideration of the lines of evidence used by prehistorians to establish the age of initial human colonization of eastern Polynesia. Contrary to orthodox methodologies that rely on radiocarbon dates from habitation sites (e.g., Spriggs and Anderson 1993), we suggest that alternative research designs relying on proxy paleoenvironmental signals of human disturbance in island ecosystems may be more successful in establishing the time frame for Polynesian settlement of those archipelagoes (e.g., Kirch and Ellison 1994).

There is no reason to suppose that the sequence of landscape change documented here for the 'Opunohu Valley is unique to Mo'orea or atypical for the Society Islands at large. Indeed, our results are quite congruent with the palynological evidence for human-induced vegetation changes on Mo'orea and Tahiti described by Parkes and Flenley (1990). Combined with the zooarchaeological evidence for substantial human impacts to the native landbird and seabird populations (Steadman 1989), these studies begin to demonstrate that the Society Islands underwent similar processes of anthropogenic ecosystem alterations that have now been documented for a variety of Pacific Islands.

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